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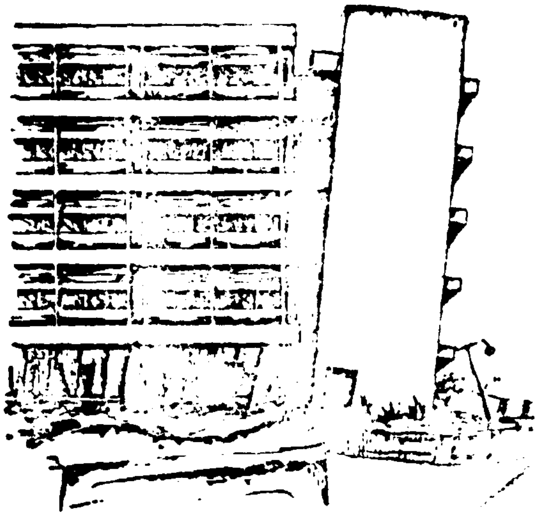

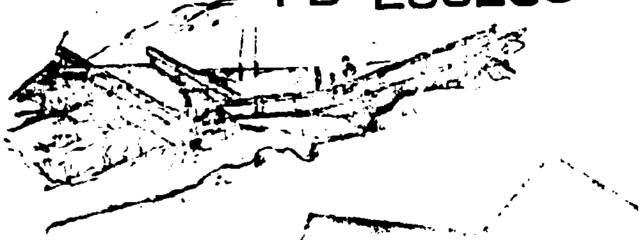

United States - Japan Panel on Wind and Seismic Effects

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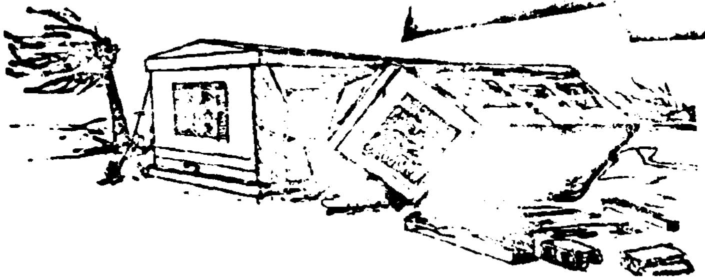

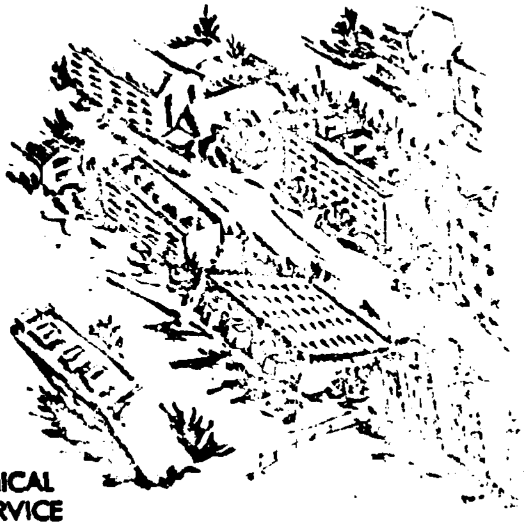

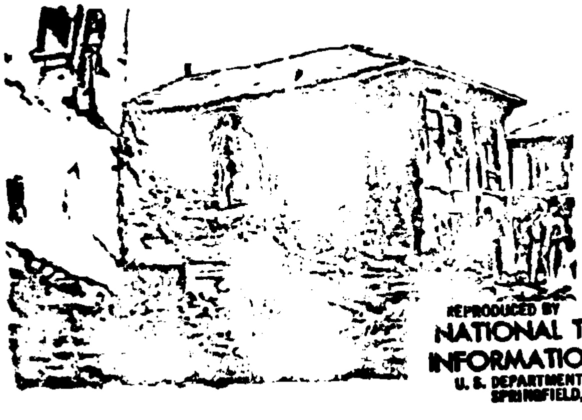

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16. Abstract (Limit: 200 words)

The development of criteria for the planning and design of networks and arrays of instrumentation to measure ground motions involves the following steps: 1) the ground motions must be estimated; 2) the costs of operations must be evaluated; and 3) the benefit derived from the data must be assessed. A similar process is also required as the first step in the process of planning instrumentation arrays for structure. The estimation of ground motions involves a determination of the tectonic setting, the seismicity of the region, and the recurrence of strong ground motions. In this basic approach to estimating ground motions, the source characteristics are modeled in terms of the recurrence of earthquakes of different magnitudes; the transmission of the motion is modeled as an attenuation of peak acceleration; and the motion at the site is obtained as a recurrence relation for particular site conditions. Most of the existing strong-motion records have been obtained in California and the technique for estimating ground motion spectra are largely based on these records. Preliminary evaluations for other regions of the United States suggest that the Mississippi embayment and Yellowstone Park regions may provide as much data, and as inexpensively, as some of the less active areas of California. High maintenance costs in Alaska offset the advantage of the generally high level of activity in that region. Instrumentation designed to study soil failures through liquefaction or landsliding can be incorporated into the regional arrays if areas subject to soil failure are identified. This instrumentation should be installed only in highly active areas.

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Planning and Design of Strong-Motion Instrument Networks

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ABSTRACT

The types of research studies that utilize strong-motion data may be classified as: source mechanism studies, ground motion studies, soil failure studies, studies of the response of typical structures (including soil-structure interaction effects), and studies of the response of equipment.

In planning networks and arrays to make these studies, criteria must be established based on the tectonic setting, the seismicity or recurrence of strong ground motions, the reliability of operations in different regions, and a cost/benefit analysis of the data that may be obtained. A review of the strong-motion records that have been obtained during the past 40 years indicates significant variations in the recurrence of strong ground motions in the seismically active regions of the western United States. When combined with instrument costs, maintenance costs, and the reliability of operations, these recurrence relations can be interpreted in terms of the cost per record for different levels of motion. The benefits to be derived from each type of study in each region need to be established.

Current plans call for additional arrays to be installed in California, the Mississippi embayment, the Yellowstone Park region, and Alaska to study the spectral characteristics of strong ground motions in these regions. Special studies of local site effects and structural response are being planned in the more seismically active regions of California. Similar criteria and planning should be applied in the establishment of arrays of strong-motion instruments on a worldwide basis.

Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

INTRODUCTION

The primary input for the design of strong-motion instrument arrays comes from the research needs in strong-motion seismology and earthquake engineering. The impetus behind much of that research is the application of the research results in engineering design and reduction of earthquake hazards. This input defines general objectives to be accomplished by an appropriately designed network but does not constrain the development of the network geographically. A secondary input comes from the mission-oriented and regulatory agencies that desire to monitor the response of critical facilities to assess their response during potentially damaging earthquakes. The location of this instrumentation is constrained to the specific structure or system being monitored but may add significant data to that obtained from a network of research instruments. The mission-oriented agencies also influence the design of the network through their need for additional research results on a timely basis.

The types of studies that utilize strong-motion data may be classified as follows:

- Studies of the source mechanism.
- Studies of the spectral characteristics of strong ground motion and of the variations of these characteristics with the nature of the source, the travel path and regional geology, or the local site conditions.
- Studies of soil failures such as soil liquefaction or landslides.
- Studies of the response of representative types of structures and interconnected systems at potentially damaging levels of response and of the influence of the foundation conditions on this response.
- Studies of the response of equipment which may be free-standing or mounted on structures.

The first of these studies is a fundamental study in seismology. The remainder conveniently divide into ground motion studies and structural response studies and may involve the use of instrumentation for either the research or monitoring function.

CRITERIA FOR NETWORK DESIGN

The development of criteria for the planning and design of networks and arrays of instrumentation to measure ground motions involves the following steps: (1) the ground motions must be estimated; (2) the costs of operations must be evaluated; and (3) the benefit to be derived from the data must be assessed. A similar process is also required as the first step in the process of planning instrumentation arrays for structures (Kojahn, 1976).

The estimation of ground motions involves a determination of the tectonic setting, the seismicity of the region, and the recurrence of strong ground motions. This is similar to the process of obtaining ground motions for use in analyses of seismic risk or for use in establishing design levels for critical facilities (Algermissen and Perkins, 1972; Hays, et al, 1975). In this basic approach to estimating ground motions, the source characteristics are modeled in terms of the recurrence of earthquakes of different magnitudes; the transmission of the motion is modeled as an attenuation of peak acceleration; and the motion at the site is obtained as a recurrence relation for particular site conditions (see fig. 1). More refined techniques are the subject of current research in which the source characteristics are modeled in terms of the expected stress drop and source dimension; the transmission of the motion is modeled in terms of the wave propagation, attenuation, and dispersion; and the site effects are modeled in terms of their influence on the spectral characteristics of the motion.

Several authors have gathered a considerable amount of data indicating that for appropriately large source regions, the recurrence of earthquakes of different magnitudes can be represented as straight lines on semi-log plots (see Algermissen, 1969, for example). On the other hand, the existing data on the attenuation of strong ground motions indicate that there is a considerable amount of scatter in the relation of the peak acceleration, velocity, or displacement to the distance from the source. Figure 2 presents the attenuation of maximum acceleration with distance from the source for all of the data recorded during the San Fernando earthquake (see Maley and Cloud, 1971). An order of magnitude difference may be seen in the peak accelerations recorded at any one distance. Figure 3 presents the attenuation of peak accelerations with distance from the epicenter for all data recorded at Ferndale, Calif., during the past 40 years. A considerable amount of scatter is evident in this plot also. This large amount of scatter in the data casts some doubt on the validity of the simplified model of transmission of motion.

The availability of data from several stations that have been installed for about 40 years provides a more direct approach to the evaluation of the recurrence of strong ground motions. For example, the results obtained from Ferndale are shown in figures 4 and 5. In figure 4, the cumulative numbers of events for which peak accelerations have exceeded selected levels are plotted versus the year in which the event occurred. The levels of peak acceleration used in figure 4 were selected to illustrate the approach used. Similar results can be obtained for each of the levels of peak acceleration recorded at this site. No attempt has been made to distinguish between foreshocks, main events, and aftershocks in compiling these data. Straight lines have been fitted to the data, and the slopes of these lines define the "events per year" for each of the selected values of peak acceleration.

All levels of peak acceleration from the complete set of records obtained at Ferndale were used to construct figure 5, in which the cumulative distribution of events per year is plotted versus the peak acceleration values. The end points are shown as circles in this figure, signifying an insufficiency in these data. (The value at a peak acceleration of 10 cm/sec^2 appears to be too low as a result of the fall off in the number of low level events that are recorded by an instrument that is triggered by the event being recorded, whereas the values for the highest peak accelerations are obtained from fewer than five events, and this is considered to be an insufficient amount of data). The amount of scatter in the data in figure 5 is relatively small compared with the amount of scatter indicated by the attenuation plots in figures 2 or 3.

Data of the type shown in figure 5 have been obtained for all of the strong-motion instrument sites that have been in place for about 40 years (table 1). Only in three cases (Ferndale, Hollister, and El Centro) are the data sufficient to provide statistically meaningful results for peak accelerations up to 100 cm/sec^2. Of equal importance, however, is the fact that at several sites in these "seismically active" areas, no estimate of recurrence could be made after 40 years of recording. For example, in the San Francisco Bay region, no reliable estimates of recurrence could be made for Golden Gate Park or San Jose, although a maximum value of greater than 100 cm/sec^2 has been recorded at each site. In the Los Angeles basin, no reliable estimates can be made for Westwood or Pasadena.

Similarly, although 12 records have been obtained at Helena, Mont., only three of these have been recorded since 1940 and none since 1960. The results in California are in sharp contrast to other estimates of recurrence that yield equal rates along most segments of the San Andreas fault. These results are also an indication of the serious difficulties in any attempt to provide a rational plan for obtaining the desired strong-motion records: potentially damaging earthquakes in any one area occur infrequently, and our basic understanding of the processes and recurrence of potentially damaging ground motions is therefore inadequate.

The cost of maintenance has been found to be about three times the cost of the instruments themselves (depreciated over a 20-year life). As a result, the procedures used in instrument maintenance need to be critically evaluated. In particular, the service interval may be lengthened if an evaluation indicates that this will not result in serious depreciation in either the quality or number of records recovered. The results of a study of the length of the service interval is shown in figure 6. In the early days of the program, a service interval of 2 months had been established. As the numbers of instruments being maintained dramatically increased in the late 1960's, this interval was perforce increased to 3 months. More recently, a general policy of servicing at a nominal 4- month interval has been adopted (a selected group of instruments are being serviced at 6-month intervals). Since the current cost figures are based on a nominal 3-month service interval, an increase to a 6-month interval will significantly decrease the maintenance costs, although they are not expected to decrease by half since it is planned that more time should be spent at each instrument when the service interval is lengthened. As a part of the evaluation of maintenance procedures, all of the older instruments are being replaced with modern instruments, and the modern types of instruments in service are being modified to bring them up to present specifications. This upgrading of the instruments should raise the lower of the two sets of lines shown in figure 6.

From the recurrence data summarized in table 1 and the average costs of instruments and maintenance ($400 per year), the costs per record for records with peak accelerations greater than specified amounts can be obtained (see table 2). At most sites, the cost doubles as the level of peak acceleration doubles. Estimates of these costs for other sites must be determined if planning criteria are to be firmly established. Since peak accelerations on the order of 200 cm/sec^2 are the minimum levels of potentially damaging motions, significant costs must be anticipated if we are to record potentially damaging levels of ground motion at many of these sites.

The benefits that will be derived from the data that will be obtained must be estimated in order to assess the proper significance of these costs. Obviously, the first set of data that will permit some of the unanswered questions regarding the nature of the strong ground motions from earthquakes in the eastern part of the United States will be of considerable benefit, whereas additional records at 50 cm/sec^2 obtained at many of the sites in California are of little benefit. It is clear, in general, that those studies that can be accomplished in the more active areas may cost one tenth as much as they would in other areas of California. Thus, studies of local site effects should be planned for Ferndale, Hollister, and El Centro, if the local soil conditions permit. Studies of low-rise buildings should be conducted in these same regions, whereas studies of high-rise buildings can be conducted only in the San Francico or Los Angeles areas.

GENERAL OBSERVATIONS

Most of the strong-motion records obtained to date have been obtained in California, and the techniques for estimating ground motion spectra are largely based on these records. Preliminary evaluations for other regions of the United States suggest that the Mississippi embayment and Yellowstone Park regions may provide as much data, and as inexpensively, as some of the less active areas of California. On the other hand, high maintenance costs in Alaska offset the advantage of the generally high level of activity in that region.

General information on the influence of local site conditions on the spectral amplitudes of ground motion may be obtained from the regional networks by placing instruments in different geologic settings or at sites with different soil conditions. More detailed studies will require an expensive instrumentation program including down-hole instruments. These should be conducted in regions where the seismic activity is sufficiently high to insure an adequate return on the investment in instrumentation and its maintenance.

Similarly, instrumentation designed to study soil failures through liquefaction or landsliding can be incorporated into the regional arrays if areas subject to soil failure are identified. Remotely recording instruments should be placed on the area of potential landslide or liquefaction as well as on nearby stable ground. Extensive instrumentation for these studies should be installed only in highly active areas.

The information necessary to assess the costs of obtaining strong-motion data from all parts of the world should be assembled so that the greatest benefit may be derived for all concerned with earthquake hazards and the loss of life that has occurred in past earthquakes.

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Table 1 - Recurrence times for stations installed for 40 years

Total Number Years	Number of Records	Maximum Accel cm/sec^2	Station Location	Years/Event		
				a > 25	a > 50	a > 100
				a in cm/sec^2		
40	45	274	FERNDALE	1.5	3	[illegible]
[illegible]	11	[illegible]	EUREKA	8	(15)	-
40	3	124	GOLDEN GATE PARK	-		
39	6	52	ALEXANDER BUILDING	(20)	-	
39	11	48	SOUTHERN PACIFIC BLDG	(10)	-	
40	6	45	OAKLAND CITY HALL	(12)	-	
40	6	56	BERKELEY	(15)	-	
41	4	138	SAN JOSE	-		
30	32	191	HOLLISTER	2	4	8
40	9	172	SANTA BARBARA	10	-	
40	3	100	WESTWOOD	-		
40	7	220	HOLLYWOOD	(30)	-	
40	9	110	OCCIDENTAL BLDG	14	-	
41	11	210	VERNON	10	20	-
41	10	250	LONG BEACH	10	(25)	-
40	4	100	PASADENA	-		
40	10	46	COLTON	12	(25)	-
41	24	314	EL CENTRO	3	6	12
41	9	30	SAN DIEGO	(20)	-	
40	13	38	BISHOP	8	-	
36	7	42	HAWTHORNE	10	-	
38	12	115	HELENA	-		

Numbers in parentheses are based on an insufficient amount of data.

Table 2 - Summary of costs per record

Station Location	Maximum Accel cm/sec^2	Cost/Record in Dollars		
		$a > 25$	$a > 50$	$a > 100$
		a in cm/sec^2		
FERNDALE	274	600	1200	2400
EUREKA	230	3200	(6000)	-
GOLDEN GATE PARK	124	-		
ALEXANDER BUILDING	52	(8000)	-	
SOUTHERN PACIFIC BLDG	48	4000	-	
OAKLAND CITY HALL	45	(4800)	-	
BERKELEY	56	(6000)	-	
SAN JOSE	138	-		
HOLLISTER	191	800	1600	3200
SANTA BARBARA	172	4000	-	
WESTWOOD	100	-		
HOLLYWOOD	220	(12000)	-	
OCCIDENTAL BLDG	110	5600	-	
VERNON	210	4000	8000	-
LONG BEACH	250	4000	(10000)	-
PASADENA	100	-		
COLTON	46	5000	(10000)	-
EL CENTRO	314	1200	2400	4800
SAN DIEGO	30	(8000)	-	
BISHOP	38	3200	-	
HAWTHORNE	42	4000	-	
HELENA	115	-		

Numbers in parentheses are based on an insufficient amount of data.

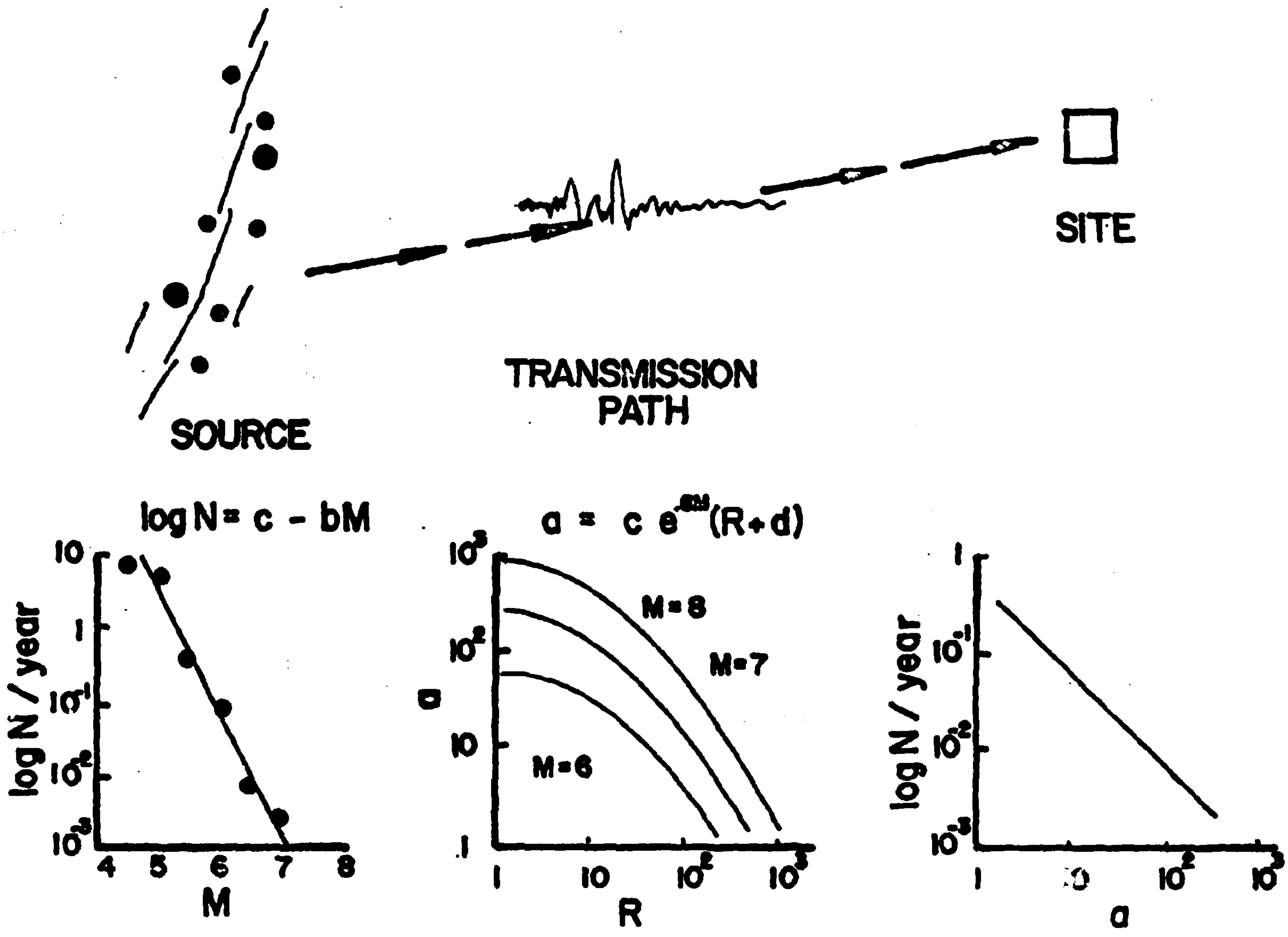

Figure 1. SCHEMATIC MODEL OF TRANSMISSION OF MOTION FROM SOURCE TO SITE

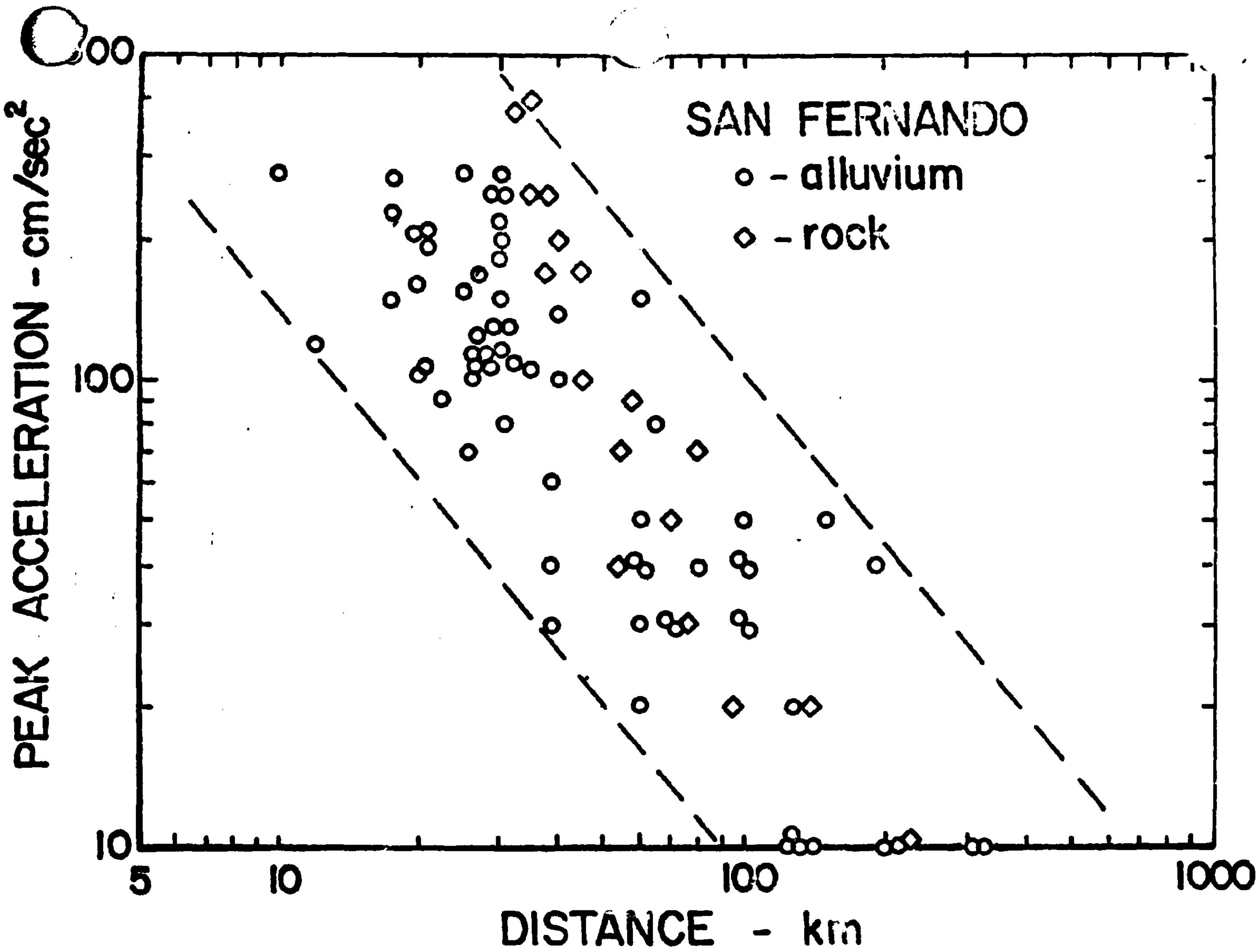

Figure 2. ATTENUATION OF PEAK ACCELERATION WITH DISTANCE - SAN FERNANDO EARTHQUAKE

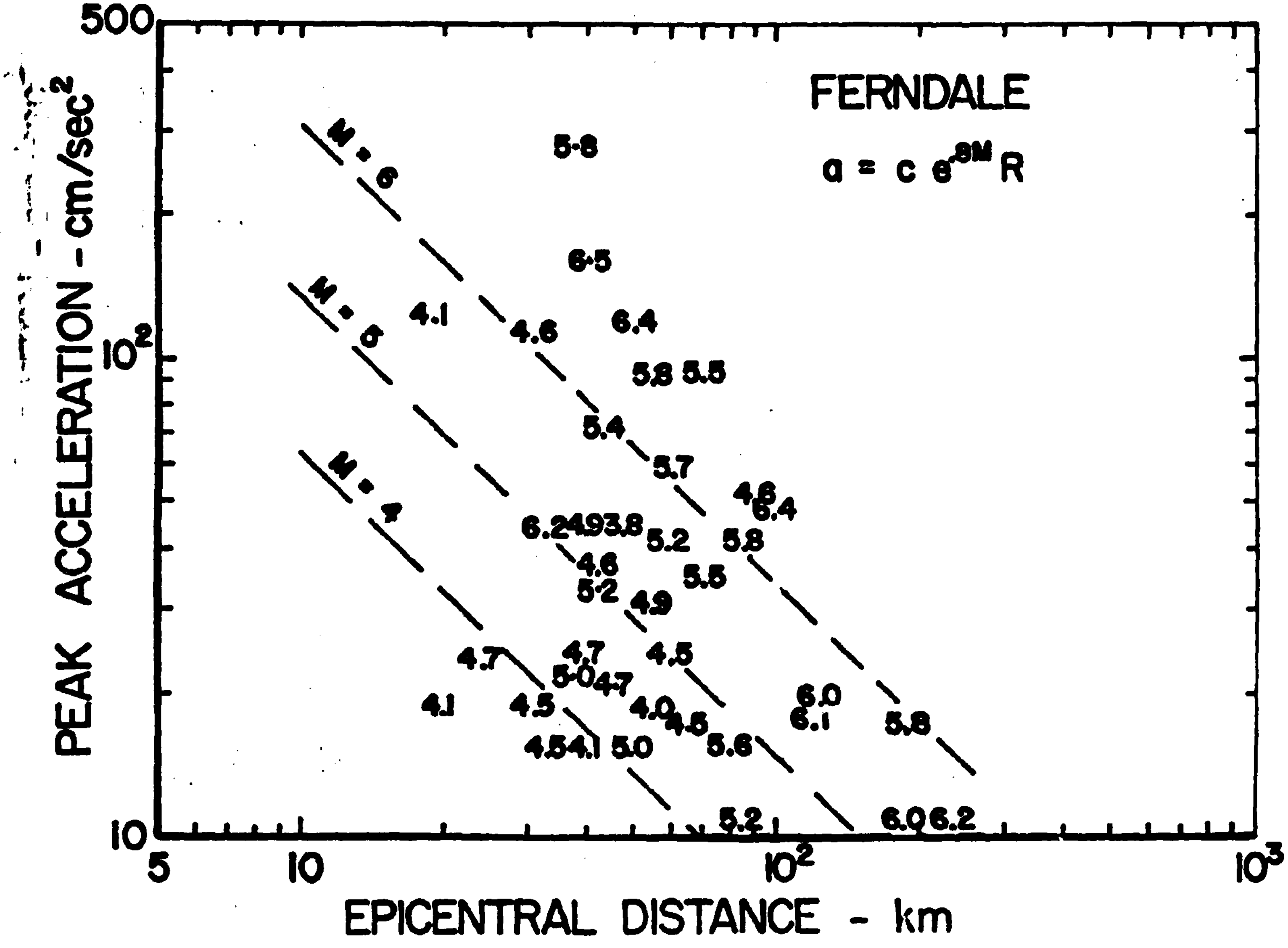

Figure 3. ATTENUATION OF PEAK ACCE ON WITH DISTANCE - FERNDALE RECORDS

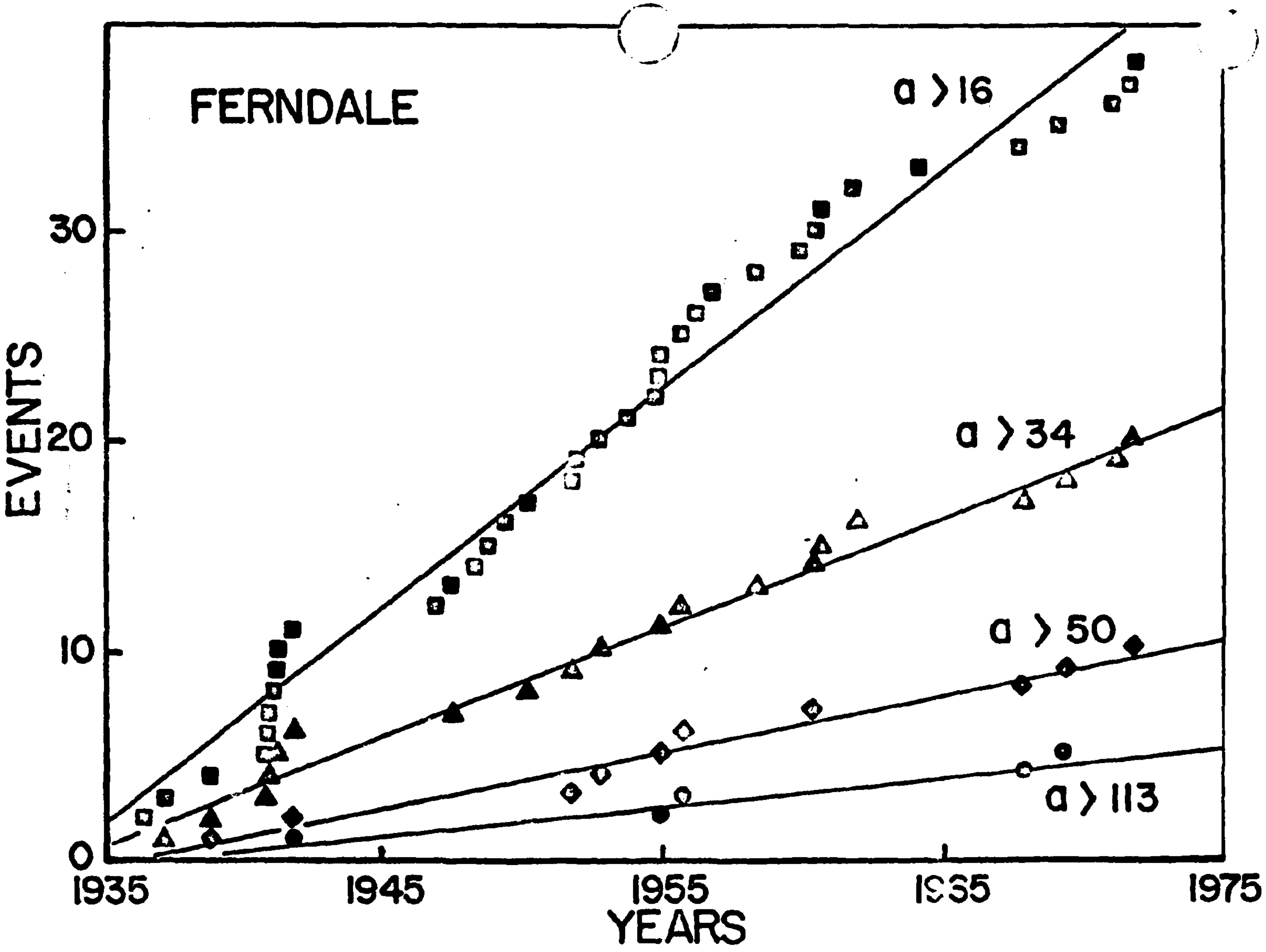

Figure 4. CUMULATIVE NUMBER OF EVENTS VERSUS TIME - FERNDALE RECORDS

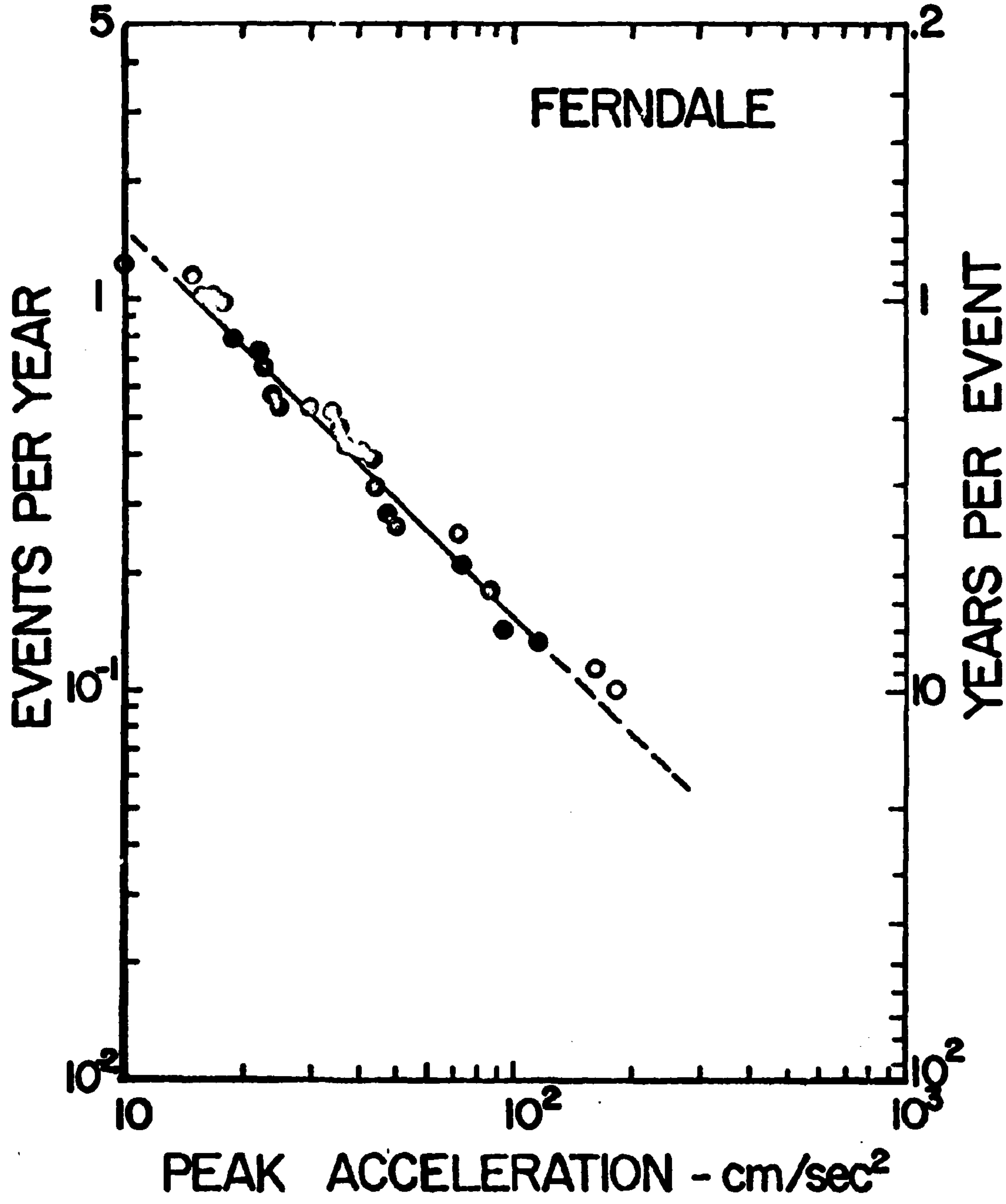

Figure 5. EVENTS PER YEAR VERSUS PEAK ACCELERATION - FERNDALE RECORDS

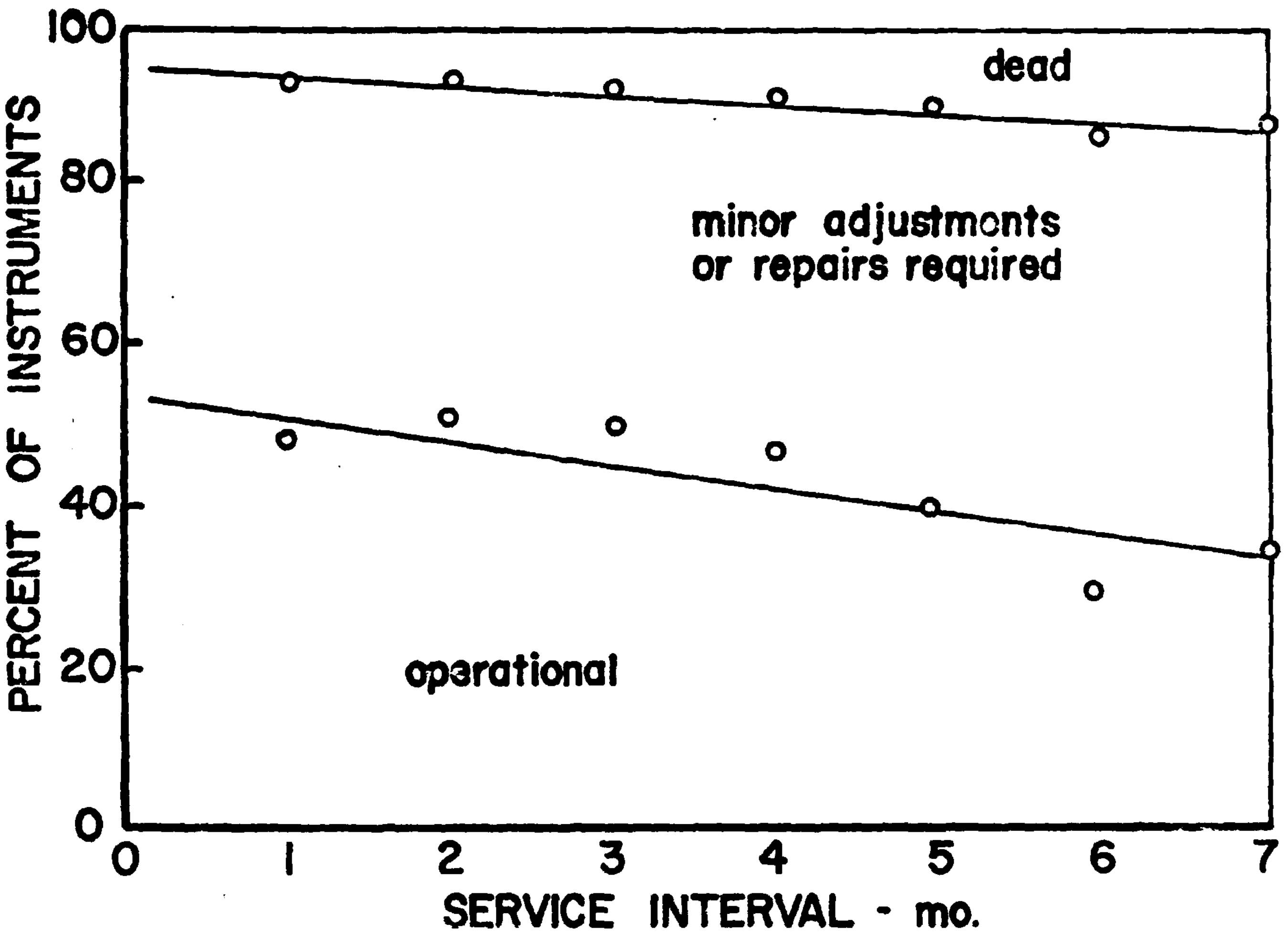

Figure 6. INSTRUMENT STATUS FOR DIFFERENT SERVICE INTERVALS